Indian Journal of Agricultural Sciences **88** (9): 1413–8, September 2018/Article

Effects of sodic water irrigation on growth, physiological relations and ion uptake in two *Ziziphus* rootstocks

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Received: 06 June 2018; Accepted: 10 July 2018

ABSTRACT

We studied the effects of sodic irrigation on growth, physiological parameters and mineral partitioning in *Zizyphus rotundifolia* (ZR) and *Z. spina-christi* (ZS) seedlings used as rootstocks for Indian jujube scion cultivars. Plants grown in normal soils were irrigated with fresh (control) and three kinds of sodic waters having residual sodium carbonate (RSC) levels of 3, 6 and 9 meq/l. Both the species displayed appreciable decreases in fresh and dry weights of shoots and roots at RSC^{iw} level of 9 meq/l. Leaf chlorophyll and chlorophyll fluorescence also decreased with increasing sodicity. While leaf proline content remained unchanged up to RSC^{iw} 3 meq/l, plants treated with 9 meq/l sodic water had nearly twofold higher leaf proline than control indicating that it could play a major role in osmotic adjustment in salt stressed plants. Na^+ and Cl^- contents increased while K^+ and Ca^{2+} declined in different plant parts with increase in RSC_{iw}. Na^+: K^+ ratio was higher at a given RSCiw in leaves and roots of ZS and in stems and roots of ZR reflecting better Na^+ exclusion by ZR. ZR leaves also had less Cl^- than ZS at a given RSC_{iw}. Owing to these adaptive traits, both the species could tolerate RSC_{iw} up to 6 meq/l.

Key words: Growth, Indian jujube, Ion uptake, Leaf physiology, Residual sodium carbonate, Salt stress, Sodic irrigation

Indian jujube (*Zizyphus mauritiana* L. family Rhamnaceae), commonly referred to as ber, is a hardy multipurpose fruit tree of Indian origin. Fruits contain appreciable amounts of vitamins (A, B complex and C) while leaves are rich in digestible crude protein (5.6%) and total digestible nutrients (49.7%) making them a nutritive fodder for animals (Pareek 2001). In India, it is commercially grown in the states of Haryana, Punjab, Uttar Pradesh, Rajasthan, Gujarat, Maharashtra, Tamil Nadu and Andhra Pradesh (Pareek 2001) and also occurs in arid parts of Pakistan, Australia and southern Africa (Arndt *et al.* 2000). Wild *Ziziphus* species like *Z. rotundifolia*, *Z. spina-christi* and *Z. nummularia* also naturally grow in arid regions (Awasthi and More 2009, Saied *et al.* 2008). Trees and shrubs of the genus *Zizyphus* reportedly endure intense heat, drought and salinity without any significant adverse impacts on growth and fruiting (Meena *et al.* 2003, Pareek 2001, Saied *et al.* 2008). Some of the traits imparting drought tolerance in different *Ziziphus* species including a deep root system capable of extracting water from the deeper soil layers (Arndt *et al*. 2000, 2001), high leaf mucilage content (7-10% dry weight) presumably releasing solutes for osmotic adjustment (Clifford *et al.* 2002) and summer deciduous habit with trees remaining leafless during hot summers (Awasthi and More 2009) could also play an important role in overcoming osmotic stress in salt stressed plants.

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Salt affected soils in India are predicted to increase from the current 6.73 M ha to 16.2 M ha by 2050 due to planned expansion in irrigation network, use of poor quality water in irrigation and climate change impacts (ICAR-CSSRI 2015). Sodic soils, constituting ≈56% of the total salt affected area in country, have variable electrical conductivity of soil saturation paste (EC_e, mostly <4 dS/m), high pH_s (>8.2) and high exchangeable sodium percentage (ESP, >15). While chlorides and sulphates of Na^+, Ca^{2+} and Mg^{2+} predominate in saline soils, sodic soils contain high amounts of CO_3^{2-} and HCO_3^- salts. In sodic soils, plant growth is adversely affected by high soil pH and ESP, poor hydraulic conductivity, water stagnation and presence of hard sub-surface calcareous pan. Problem of sodic groundwater is also widespread in many sodicity affected areas of India (Sharma *et al.* 2016). Sodicity hazard of irrigation water can be assessed by measuring the residual sodium carbonate (RSC). In India, irrigation waters having RSC> 2.5 meq/l are classified as 'sodic' and their continued use in irrigation can cause irreversible decline in soil properties.

Several authors have investigated the morphological and physiological bases of salinity tolerance in *Z. rotundifolia* (Gupta *et al.* 2002, Meena *et al.* 2003) and *Z. spina-christi* (Nejat and Sadeghi 2016, Shekafandeh and Takhti 2013, Sohail *et al.* 2009). However, scantly information is available on morpho-physiological traits imparting sodicity tolerance in these species. In sodic soils, growth and establishment of Indian jujube plants can be hampered by surface water stagnation resulting in tree mortality (Dagar *et al.* 2001). In areas where sodic groundwater is the only source of irrigation, problems of surface crusting, soil dispersion and waterlogging may appear repeatedly requiring periodical applications of amendments and subsequent leaching with the fresh water. Availability of salt tolerant rootstock and scion cultivars can ensure stable fruit yields while greatly reducing the dependence on soil amendments and unsustainable use of good quality water. Accordingly, this study was conducted to understand the effects of sodic water irrigation on *Z. rotundifolia* and *Z. spina-christi*; two commonly used rootstocks for Indian jujube scion cultivars in India.

MATERIALS AND METHODS

This study was conducted during 2016-17 and 2017-18 at ICAR-CSSRI Experimental Farm, Karnal (29°43'N, 76°58'E; 245 m above the mean sea level) in a shade house under natural conditions. Six-month old seedlings of two *Ziziphus* spp., namely, *Z. rotundifolia* (ZR) and *Z. spina-christi* (ZS) were used as the experimental material. Fruits of ZR and ZS obtained from ICAR-Central Institute of Arid Horticulture, Bikaner (Rajasthan), India were used for extracting the seeds. Freshly extracted seeds were sown in nursery polybags (2 kg size) for germination. Six-month old seedlings were transferred to ceramic pots containing 16 kg normal soil (EC_e: 0.8 dS/m; pH_s: 8.3). After transplanting, seedlings were pruned to a uniform height. Sodic water treatments were imposed one month after transplanting and were continued until 180 days at 15 days interval. There were four treatments including normal water (control) and three kinds of sodic water having residual sodium carbonate (RSC) levels of 3, 6 and 9 meq/l. Measured quantities of $NaHCO_3$, $CaCl_2.2H_2O$ and $MgCl_2.6H_2O$ salts were dissolved in water to obtain the desired RSC levels as per methodology given in Chawla (2013). These levels of RSC reflect the sodicity in groundwater in several parts of north-western India where Indian jujube is commonly grown. Chlorophyll content in leaves was recorded using SPAD meter on two topmost fully expanded leaves. Same leaves were used for measuring photochemical efficiency (F_v/F_m- chlorophyll fluorescence) using a portable pulse modulated fluorescence meter after dark adaptation of the leaves for 15 min. Leaves were gently detached from the plants, placed in an ice box and brought to the laboratory for estimating total chlorophyll, proline and total soluble proteins by the methods of Hiscox and Israelstam (1979), Bates (1973) and Bradford (1976), respectively, using an UV-VIS spectrophotometer. Plants were gently removed from the soil followed by one washing with normal water and two washings with the distilled water to remove dust and salt particles. Stem and root lengths were determined using the measuring tape. After recording the shoot and root fresh weights, samples were dried to a constant weight at 60º in an electric oven (NSW, India) to measure the dry weights. Leaf, stem and root samples were crushed in a hammer mill and stored at the room temperature. Fifty mg of powdered material was extracted with 1 M HNO_3 at 100ºC. Na^+ and K^+ contents were determined through flame photometry. Leaf chloride content was determined volumetrically by the modified method of Chhabra (1973). The experiment was laid out in a completely randomized block design with three replications. Data were analyzed using Indian NARS Statistical Computing Portal (http://stat.iasri.res.in/sscnarsportal). For comparison of means, Fisher's Least Significant Difference (LSD) test was used at 5% level of significance.

RESULTS AND DISCUSSION

Plant growth

In this experiment, six month old seedlings of *Z. rotundifolia* (ZR) and *Z. spina-christi* (ZS) were treated with normal and sodic waters having RSC levels of 3, 6 and 9 meq/l. In both the species, stem length only marginally declined up to RSC_{iw} level of 6 meq/l. Even at the highest RSC_{iw} level (9 meq/l), stems were only ≈15% and 20% shorter in ZS and ZR, respectively, compared to control. Root length did not significantly decline with increasing RSC in irrigation water in both the species (Table 1). Pandey *et al.* (1995) found that plant growth was not much affected in *Z. rotundifolia* seedlings in a moderately sodic soil (47% ESP) even after 120 days of exposure. At 70% soil ESP, however, plant height and stem girth were 57% and 31% less, respectively, than control (30% soil ESP). Although effects of sodicity stress on plant growth in *Z. spina-christi* are not known, Sohail *et al.* (2009) observed that seedling height decreased by 37% and 57% at 80 and 160 mM NaCl levels, respectively. Despite nominal reductions in stem and root lengths, both the species displayed appreciable decreases in fresh and dry weights of shoots and roots with increase in RSC_{iw}. At highest RSC_{iw} (9 meq/l), shoot fresh and dry weights were ≈18% and 25% lower in ZS, and ≈27% and 43% lower in ZR than respective control. Corresponding reductions in root fresh and dry weights were ≈40% in ZS, and ≈29% and 46% in ZR. In both ZS and ZR, branching and leaf production were more adversely affected resulting in sparse growth and consequent reductions in plant fresh and dry weights. Similarly, despite nominal reductions in length, main tap roots in both the species produced smaller lateral roots and fewer root hairs (data not shown). Singh *et al.* (2018) found that plant height and stem girth were less affected but shoot and leaf emergence considerably declined in salt stressed guava (*Psidium guajava* L.) and bael (*Aegle marmelos* Correa) plants.

Leaf physiological parameters

Chlorophyll content of leaves, expressed as SPAD (Soil Plant Analysis Development) value, decreased by ≈13%, 22% and 25% in ZS, and by ≈11%, 18% and 22% in ZR

Table 1 Effects of sodic water irrigation on plant growth in ber rootstocks

Rootstock	Treatment (RSC; meq/l)	Stem length (cm)	Root length (cm)	SFW (g)	SDW (g)	RFW (g)	RDW (g)
Z. spinachristi	Control	98.7^{a}	41.3	92.7^{a}	45.0^{a}	75.3^{a}	46.0^{a}
	3.0	88.7^{b}	40.3	86.7^{b}	40.0^{b}	61.0^{b}	40.7^{b}
	6.0	88.3^{b}	38.0	81.7^{c}	37.0b^{c}	48.3^{c}	30.7^{c}
	9.0	84.0^{b}	36.7	75.7^{d}	33.7^{c}	44.7^{c}	27.7^{d}
	LSD at 5%	5.8	NS	2.6	4.6	5.9	2.2
Z. rotundifolia	Control	86.0^{a}	27.3	86.7^{a}	48.0^{a}	76.0^{a}	42.7^{a}
	3.0	83.0^{a}	29.3	81.0^{b}	45.3^{a}	79.3^{a}	40.7^{a}
	6.0	74.0^{b}	27.7	75.0^{c}	39.7^{b}	66.0^{b}	33.3^{b}
	9.0	68.7^{b}	23.3	63.0^{d}	27.3^{c}	54.0^{c}	23.0^{c}
	LSD at 5%	6.5	NS	3.3	4.4	4.1	4.2

Means (n=3) with at least one letter common are not statistically significant using Fisher's Least Significant Difference. SFW- Shoot fresh weight, SDW- Shoot dry weight, RFW- Root fresh weight, RDW- Root dry weight.

at RSC_{iw} levels of 3, 6 and 9 meq/l, respectively, compared to control (Table 2). In a previous study, SPAD readings in *Z. spina-christi* leaves were found to be 27-32% lower at 80 and 160 mM NaCl levels than control (Sohail *et al.* 2009). Total leaf chlorophyll determined using standard laboratory procedure (Hiscox and Israelstam 1979) also declined though differences between control and different RSC_{iw} treatments were rather small (Table 2). Depending on salt composition and other factors, *Z. mauritiana* plants exhibit either higher (Hooda *et al.* 1990) or lower (Awasthi *et al.* 1997) Mg^{2+} levels than salt-free plants. Use of Mg salts ($MgCl_2$ and $MgSO_4$) in saline solutions may increase Mg^{2+} uptake by plants (Hooda *et al.* 1990). We observed partial loss of leaf chlorophyll with increasing sodicity which seems to be due to factors other than Mg deficiency because $MgCl_2.2H_2O$ was one of the salts used to induce sodicity. Depending on crop, chlorophyll concentration and SPAD values may exhibit either a strong or weak correlation and may also vary when chlorophyll concentration is expressed per unit fresh weight; as in the present case. Some reasonable explanations for this non-linear relationship include non-uniform distribution of chlorophyll across the leaf surface and differential scattering and reflection of photons at different wavelengths (Uddling *et al.* 2007). Chlorophyll fluorescence, a measure of photochemical efficiency expressed as the ratio of variable: maximal fluorescence (Fv/Fm) also significantly decreased with increase in the sodicity of irrigation water. At RSC_{iw} level of 9 meq/l, CF was ≈19.0% and 8.0% less than control in ZS and ZR, respectively (Table 2). Non-stressed healthy plants generally exhibit an Fv/Fm ratio between 0.75 and 0.85 (Lucena *et al.* 2012). Among citrus genotypes, FA 5 seedlings showed ≈7.0% reduction in Fv/Fm after 94 days of salt treatment. However, salt induced decreases in Fv/Fm ratio were much higher (≈30.0%) in Citranges (Lopez-Climent *et al.* 2008) reflecting inherent genotypic differences in Fv/Fm ratio under saline conditions.

Leaf proline levels consistently increased with increases in RSC_{iw} indicating that proline could play a major role in osmoregulation by salt stressed ZS and ZR seedlings.

Table 2 Effects of sodic water irrigation on leaf chlorophyll, chlorophyll florescence, proline and total soluble proteins in ber rootstocks

Rootstock	Treatment (RSC; meq/l)	SPAD	Total Chl. (mg/g FW)	CF	Proline (mg/g FW)	TSP (mg/g FW)
Z. spinachristi	Control	47.1^{a}	0.19^{a}	0.64^{a}	0.55^{c}	17.3^{a}
	3.0	40.9^{b}	0.16^{b}	0.61^{b}	0.62^{c}	15.3^{b}
	6.0	36.8b^{c}	0.16^{b}	0.57^{c}	0.93^{b}	10.1^{c}
	9.0	35.2^{c}	0.14^{c}	0.52^{d}	1.21^{a}	4.2^{d}
	LSD (P=0.05)	4.2	0.01	0.02	0.11	1.7
Z. rotundifolia	Control	45.8^{a}	0.19	0.62^{a}	0.55^{c}	16.3^{a}
	3.0	40.9^{b}	0.16	0.61^{b}	0.68^{bc}	14.2^{b}
	6.0	37.6^{bc}	0.14	0.60^{b}	0.86^{ab}	13.5^{c}
	9.0	35.8^{c}	0.13	0.57^{c}	1.07^{a}	9.0^{d}
	LSD (P=0.05)	4.04	NS	0.01	0.22	0.65

Means (n=3) with at least one letter common are not statistically significant using Fisher's Least Significant Difference. Chl.- Chlorophyll, CF- Chlorophyll fluorescence, TSP- Total soluble proteins.

While leaf proline content remained unchanged up to RSC_{iw} 3 meq/l, both the species showed nearly twofold higher proline at 9 meq/l RSC_{iw} than control (Table 2). Proline accumulation often improves osmotic adjustment in salt treated plants. Leaf proline was about 1.6-times higher than control in salt stressed (15.0 dS/m) *Z. rotundifolia* and *Z. nummularia* seedlings (Gupta *et al.* 2002). Proline accumulation in leaves plays a critical role in the acclimation of *Z. spina-christi* plants to salt stress (Nejat and Sadeghi 2016). Proline content increased with increasing salinity in *Z. mauritiana* seedlings (Bhatt *et al.* 2008). In contrast to proline, total soluble proteins (TSP) in leaves decreased with increase in RSC_{iw}. At 9 meq/l RSC_{iw}, ZS and ZR displayed about 76% and 45% less TSP compared to the respective control (Table 2). Total soluble protein content may either increase or decrease or may remain unaffected in salt stresses plants (Doganlar *et al.* 2010). In salinized *Z. spina-christi* seedlings, leaf TSP content marginally increased up to 9.6 dS/m salinity but declined at 12.3 dS/m compared to control (Nejat and Sadeghi 2016). In mulberry (*Morus alba* L.), TSP increased up to 4 dS/m salinity but decreased at higher salinities (8 and 12 dS/m) regardless of the genotype (Agastian *et al.* 2000).

Ion uptake and partitioning

Sodium ($Na^{+)}$) content significantly increased in different vegetative parts with increase in RSC_{iw} in both ZS and ZR. Leaf Na^+ increased by ≈18%, 39% and 70% in ZS and by ≈8%, 33% and 62% in ZR over control at RSC_{iw} levels of 3, 6 and 9 meq/l indicating differences for Na^+ exclusion from leaves. Although Na^+ levels were invariably higher in stems of ZR than in ZS, salt induced increases in stem Na^+ were much higher in ZS. Compared to non-stressed plants, stem Na^+ increased by ≈36%, 164% and 209% in ZS, and by ≈19%, 39% and 52% in ZR at RSC_{iw} levels of 3, 6 and 9 meq/l, respectively. In roots, Na^+ increased by ≈52%, 86% and 224% in ZS, and by ≈5%, 18% and 84% in ZR than control at RSC_{iw} levels of 3, 6 and 9 meq/l, respectively. These observations suggest Na^+ exclusion by roots in ZR, and Na^+ retention in stems and roots in ZS resulting in reduced translocation to the leaves. Although leaf K^+ declined in both species with increasing RSC_{iw}, reductions were relatively lesser in ZR than in ZS. For example, leaf K^+ decreased by ≈43% in ZS and by ≈35% in ZR at the highest RSC_{iw} level (9 meq/l). A similar trend was noted for stem and root K^+ contents as ZR showed much lower decreases in K^+ than ZS at different RSC_{iw} levels. Owing to higher Na^+ levels and the consequent K^+ depletion, ZS plants showed considerable increase in Na: K ratio in different plant parts at a given RSC_{iw} level. In leaves, stems and roots, Na: K ratio was nearly three-, seven- and tenfold higher in ZS while the corresponding increases were only about threefold in ZR (Table 3).

Restricted translocation of Na^+ from roots to shoots as well as selective uptake of K^+ has previously been reported in salt stressed *Z. rotundifolia* plants (Gupta *et al.* 2002, Meena *et al.* 2003). Depending on experimental conditions, salinity stress may either considerably (Sohail *et al.* 2009) or slightly (Nejat and Sadeghi 2016) increase Na^+ accumulation in *Z. spina-christi* plants, but K^+ mostly remains unaffected. These observations suggest Na^+ exclusion mechanism in both *Z. rotundifolia* and *Z. spina-christi*. Despite Na^+ accumulation in the foliage, lack of ion-specific toxicities points to the probable role of Na^+ ions in osmotic adjustment in salinized plants. Selective uptake of K^+ may also help salt treated plants partly negate the adverse effects of Na^+. Results of this study with stem Na^+ concentrations remaining below 0.5% while root Na^+ reaching 0.7-0.9% at RSC_{iw} 9 meq/l in both the species are consistent with the findings of Sohail *et al.* (2009) who reported stem and root Na^+ concentrations of ≈0.6-0.7% in *Z. spina-christi* plants up to 120 mM NaCl level. In contrast, our results for leaf Na^+ accumulation are different from Sohail *et al.* (2009) which can be attributed to the differences in experimental conditions, method and duration of salt treatment and composition of salt solutions. In a related species *Z. jujuba*, Na^+ threshold (%DW) for

Table 3 Effects of sodic water irrigation on Na^+ and K^+ (%DW) partitioning in different plant parts in jujube rootstocks

Rootstock	Treatment (RSC; meq/l)	Leaf			Stem			Root		
		Na^+	K^+	Na: K ratio	Na^+	K^+	Na: K ratio	Na^+	K^+	Na: K ratio
Z. spina-christi	Control	0.33^d	2.1^a	0.16^d	0.11^d	1.7^a	0.06^d	0.29^d	2.6^a	0.11^d
	3.0	0.39^c	1.9^b	0.21^c	0.15^c	1.4^b	0.11^c	0.44^c	1.4^b	0.31^c
	6.0	0.46^b	1.2^c	0.37^b	0.29^b	0.9^c	0.31^b	0.54^b	0.9^c	0.57^b
	9.0	0.56^a	1.2^c	0.47^a	0.34^a	0.8^d	0.44^a	0.94^a	0.9^c	1.10^a
	LSD (P=0.05)	0.01	0.15	0.03	0.02	0.09	0.03	0.04	0.12	0.04
Z. rotundifolia	Control	0.24^d	2.0^a	0.12^d	0.31^d	1.9^a	0.17^c	0.38^c	1.8^a	0.22^c
	3.0	0.26^c	1.6^b	0.16^c	0.37^c	1.6^b	0.24^c	0.40b^c	1.4^b	0.28^c
	6.0	0.32^b	1.6^b	0.20^b	0.43^b	1.3^c	0.34^b	0.45^b	1.2^c	0.38^b
	9.0	0.39^a	1.3^c	0.30^a	0.47^a	0.8^d	0.58^a	0.70^a	0.9^d	0.75^a
	LSD (P=0.05)	0.01	0.21	0.03	0.02	0.19	0.08	0.06	0.16	0.09

Means (n=3) with at least one letter common are not statistically significant using Fisher's Least Significant Difference.

Table 4 Effects of sodic water irrigation on Ca^{2+} and Cl^- (% DW) partitioning in ber rootstocks

Rootstock	Treatment (RSC; meq/l)	Ca^{2+}			Cl^-		
		Leaf	Stem	Root	Leaf	Stem	Root
Z. spina-christi	Control	1.05a	0.44^a	0.61^a	2.01^c	3.31^b	3.20^c
	3.0	0.88b	0.33^b	0.55^b	2.72^b	3.40^b	4.50^b
	6.0	0.84b	0.31^b	0.32^c	3.20^b	4.14^a	5.33^a
	9.0	0.63c	0.25c	0.29^d	4.38^a	4.38^a	5.54^a
	LSD (P=0.05)	0.07	0.04	0.01	0.49	0.62	0.65
Z. rotundifolia	Control	0.76a	0.49^c	0.79^a	1.54^c	2.49^b	2.84^c
	3.0	0.70b	0.64^b	0.76^a	1.89^c	2.60^b	4.14^b
	6.0	0.59c	$0.72a^b$	0.70^{ab}	2.37^b	3.33^a	$4.50a^b$
	9.0	0.57c	0.75^a	0.63^b	2.96^a	3.79^a	4.97^a
	LSD (P=0.05)	0.04	0.09	0.1102	0.46	0.49	0.66

Means (n=3) with at least one letter common are not statistically significant using Fisher's Least Significant Difference.

normal growth and flowering was found to be 0.40% in leaves and 0.27% Na^+ in roots (Meir *et al.* 2014). In this experiment, leaf Na^+ was ≈0.5% in ZS and ≈0.3% in ZR up to RSC_{iw} 6 meq/l suggesting efficient Na^+ exclusion by *Z. rotundifolia*.

After six months of sodic irrigations, leaf, stem and root Ca^{2+} concentrations declined by ≈40%, 43% and 52% at 9 meq/l RSC_{iw} than control in ZS. In ZR, while leaf Ca^{2+} dropped only by ≈25%, stem Ca^{2+} consistently increased while root Ca^{2+} was unaffected (Table 4). Bhat *et al.* (2008) observed that Ca^{2+} concentrations in different plant parts only marginally declined up to 6 dS/m salinity in *Z. mauritiana* plants. Awasthi *et al.* (1997) reported that Ca and Mg levels dropped in budded Indian jujube plants in sodic soils but increased in saline soils. Hooda *et al.* (1990) also found increased Ca and Mg levels in salinized plants of *Z. mauritiana* cv. 'Umran'. Similarly, Meir *et al.* (2014) noted that salinity did not hamper N and P contents in leaves and roots of *Z. jujube* trees. These observations imply that salt stress may have little adverse impacts on uptake of essential mineral ions like Ca by different jujube species.

Leaf, stem and root Cl^- contents also increased with increasing sodicity in irrigation water. In ZS, leaf Cl^- consistently and significantly increased with increase in RSC_{iw}. In ZR, leaf Cl^- was unaffected up to RSC_{iw} level of 3 meq/l. At the highest RSC_{iw} (9 meq/l), ZS and ZR plants exhibited ≈118% and 92% higher leaf Cl^- than respective control. In both ZS and ZR rootstocks, stem and root Cl^- contents increased up to 6 meq/l RSC_{iw} but did not increase further suggesting an upper limit to Cl^- uptake by roots and subsequent translocation to stem tissues (Table 4). Notably, Cl^- accumulation in different plant parts was always higher than corresponding Na^+ levels at a given sodicity level. Several fruit crops like citrus, stone fruits, grapes and avocado often absorb much larger quantities of Cl^- than Na^+ at equivalent salinity levels reflecting higher exclusion efficiency for Na^+. In crops like citrus, Cl^- uptake can often exceed that of cations combined by twofold (Singh and Sharma 2018). Sohail *et al.* (2009) observed that leaf, stem and root Cl^- concentrations were invariably higher compared to that of Na^+ in salt treated *Z. spina-christi* plants. They also found that Cl^- contents abruptly increased up to 80 mM NaCl but differences for Cl^- concentration between 80 and 120 mM NaCl levels were non-significant. In *Z. jujuba*, leaf Cl^- threshold (% DW) for normal growth and flowering was found to be 2.7% (Meir *et al.* 2014) which is close to the leaf Cl^- values reported here. Leaf, stem and root Cl^- contents in different plant parts of grafted and non-grafted cultivars of *Z. spina-christi* increased with increase in salinity; albeit to a greater degree in roots than in stems and leaves (Shekafandeh and Takhti 2013) which corroborates our results.

Data showed that plant growth in *Z. spina-christi* and *Z. rotundifolia* only marginally declined up to RSC level of 6 meq/l. Leaf proline appeared to be the major osmolyte; especially in *Z. spina-christi* plants. Na^+: K^+ ratio was higher at a given RSC_{iw} in leaves and roots of ZS and in stems and roots of ZR reflecting better Na^+ exclusion by ZR. Cl^- uptake was invariably much higher compared to Na^+ indicating that Cl^- ions could play a major role in osmotic adjustment under saline conditions. Results suggest that *Z. spina-christi* can also be used as rootstock for alleviating salt stress in Indian jujube scion cultivars.

ACKNOWLEDGMENT

This study was funded by RKVY, Haryana. Authors are thankful to Director, ICAR-CSSRI, Karnal for providing the logistic support.

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